Power Amplifier Linearization Techniques: An Overview

Workshop on RF Circuits for 2.5G and 3G Wireless Systems

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List of Topics

- Motivation for using linearization
- Linearization as a theoretical problem
- Survey of commonly employed techniques

Linearity vs. Power Efficiency

Power efficiency ⇨ *Battery lifetime*
Thermal management

Linearity ⇨ **Sophisticated Modulation Techniques** ⇨ *Spectral efficiency*

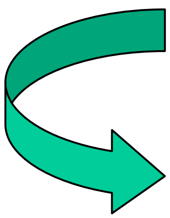
PA Tradeoffs

- **Power Efficiency => Switching PA's (class D, E, F)**

- **Linearity => Class A, AB, B, C.**

Can nonlinear system theory help?

Theory of time-invariant (or, "stationary") nonlinear systems is well-developed.



Volterra series, Weiner systems, Hammerstein systems...

Problem: *Intensely* formal, and usually lacks the conceptual clarity that leads to design insight.

Example: 3rd order nonlinearity in a two-tone experiment

The input tones:

$$2\alpha \cos \omega_1 t + 2\beta \cos \omega_2 t$$

$$\alpha e^{j\omega_1 t}, \alpha e^{-j\omega_1 t}, \beta e^{j\omega_2 t}, \beta e^{-j\omega_2 t}$$

Output sinusoids at: **$3\omega_1$, $3\omega_2$, $2\omega_1-\omega_2$, $2\omega_2-\omega_1$, $2\omega_1+\omega_2$, $2\omega_2+\omega_1$**

$H_3(s_1,s_2,s_3)$

An output product: $\alpha^2 \beta H_3(j\omega_1, j\omega_1, -j\omega_2) e^{j(2\omega_1 - \omega_2)t}$

So where does the theory leave us?

- Odd order nonlinearities cause distortion products that are in-band.

- Outrageous behavior in the lab may imply that the device under test is *not* time-invariant.

Design implications:

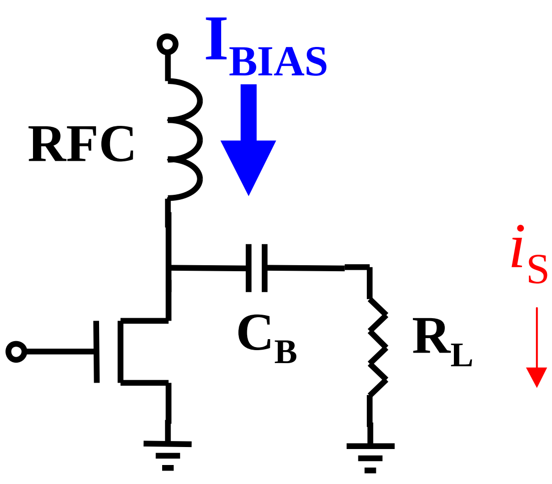
- An important measure of the strength of a given linearization method is its robustness to poor characterization of the PA.

- Design, if possible, to “force” PA to behave as a benign nonlinear system (e.g., look for ways to preserve time-invariance).

Technique I: Power Backoff

For “small” inputs, this term is dominant.

Basic principle: $V_o(x) = a_0 + a_1 x + a_2 x^2 + \cdots = \sum_{n=0}^{\infty} a_n x^n$



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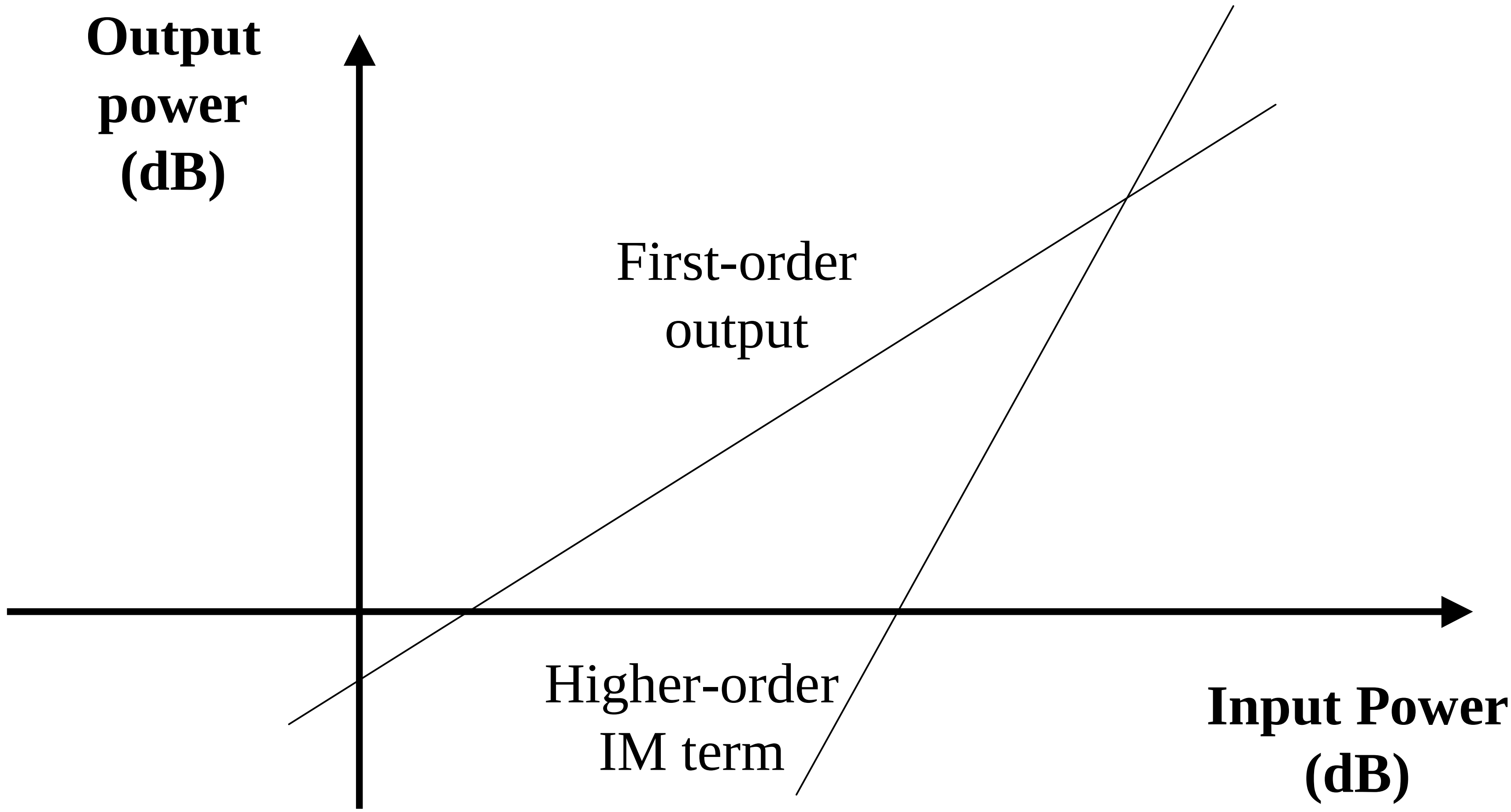
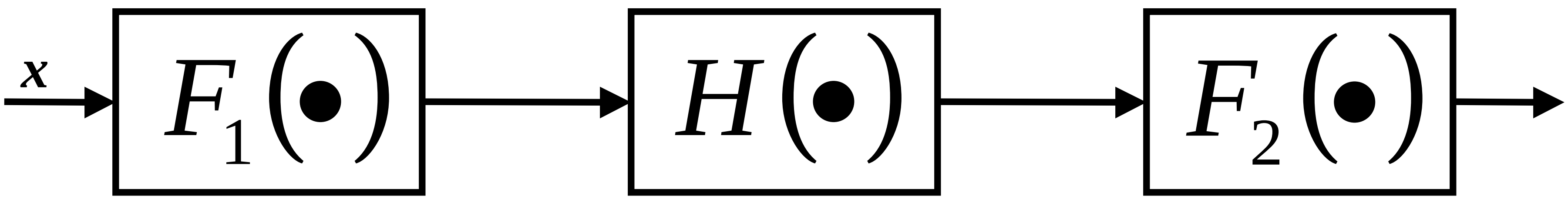
Low efficiency

Power Backoff, cont.



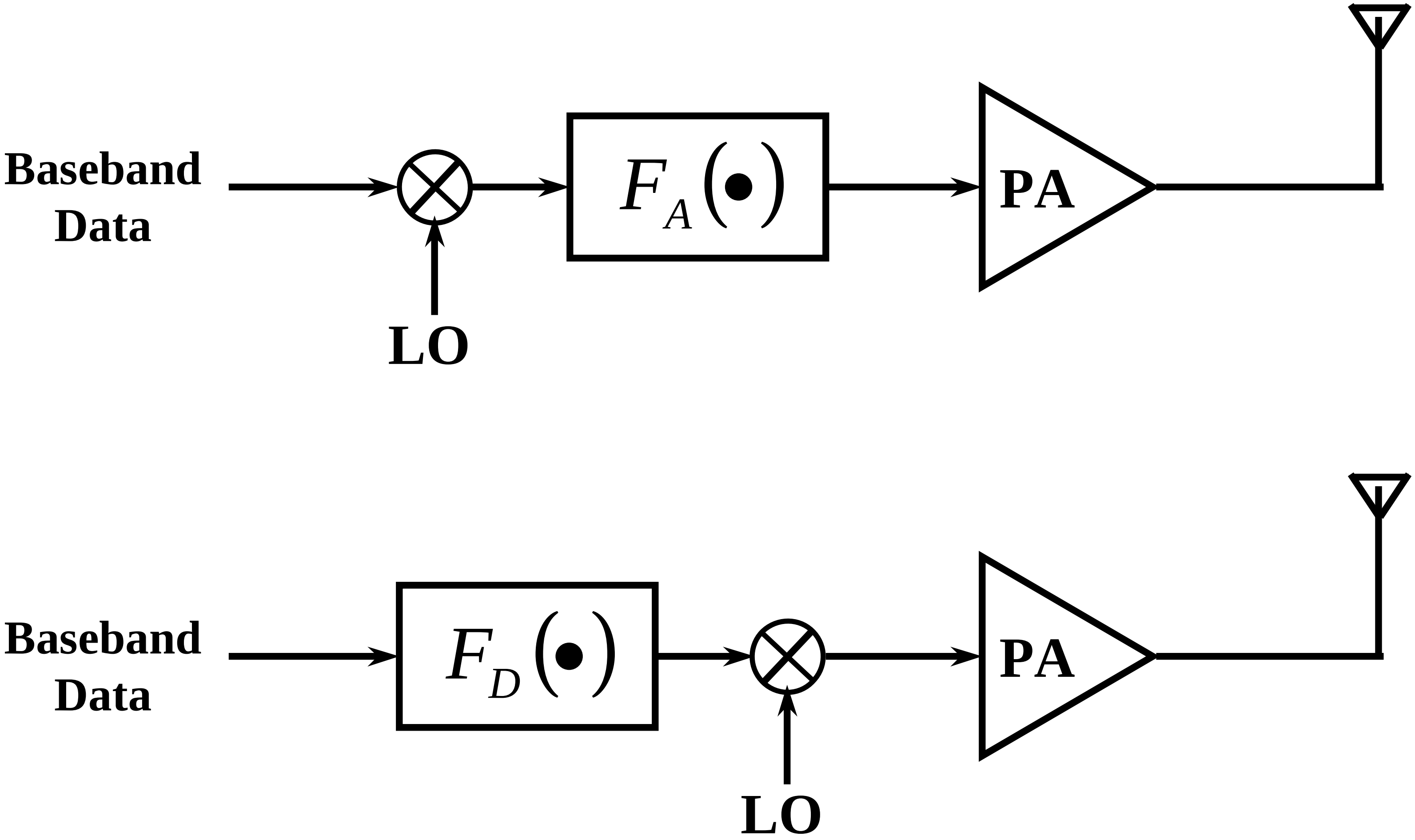
Corrective distortion: predistortion and/or postdistortion



(Power amplifier)

Most general problem: choose F_1 and F_2 such that $F_2(H(F_1(x)))$ is a linear function of the input variable x.

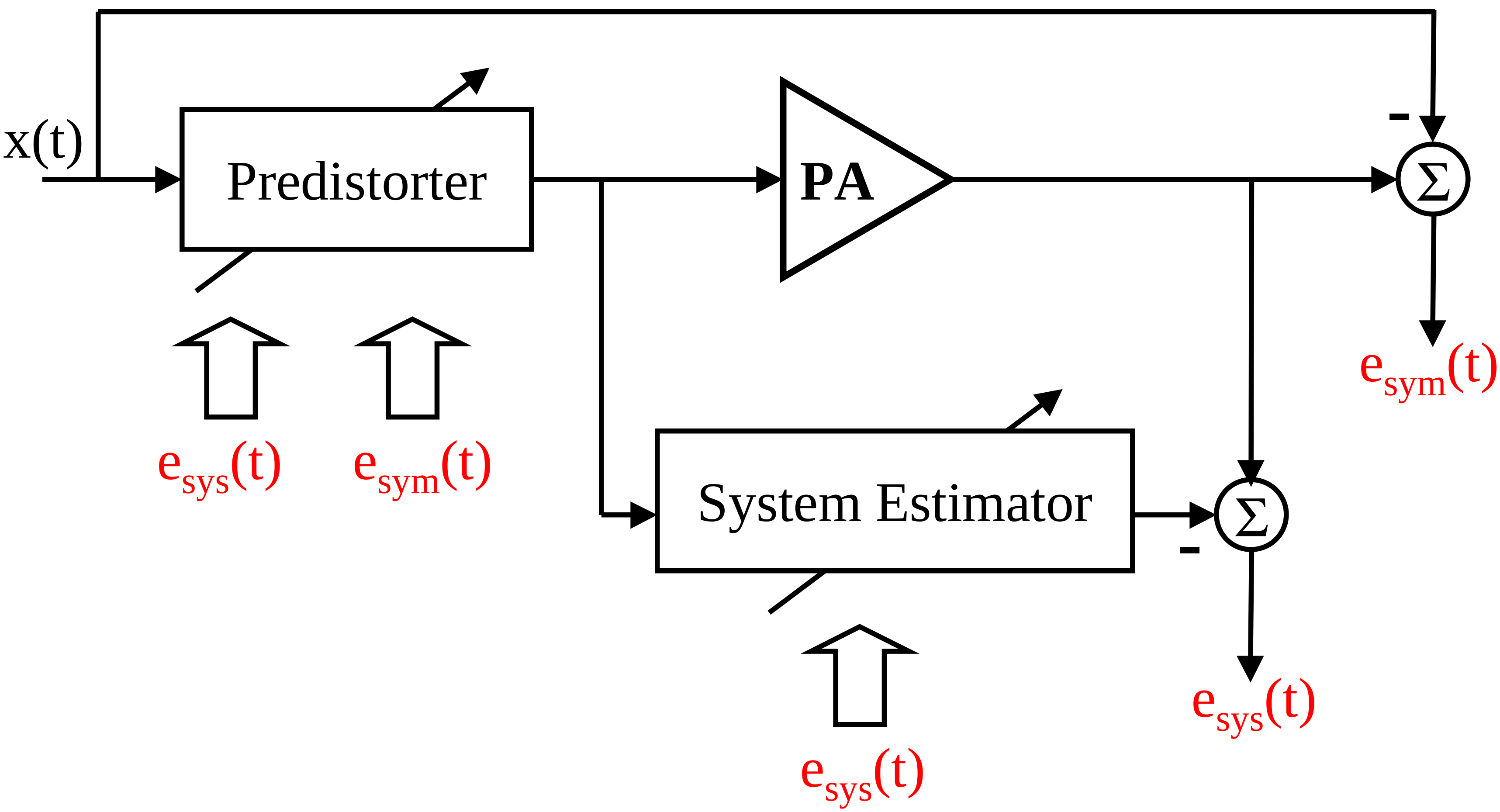
Technique II: Predistortion



Key design issues for a predistorter:

- In analog case, how to realize the predistortion function.
- Initial calibration or training.
- Sensitive to drift.

Technique III: Adaptive Predistortion



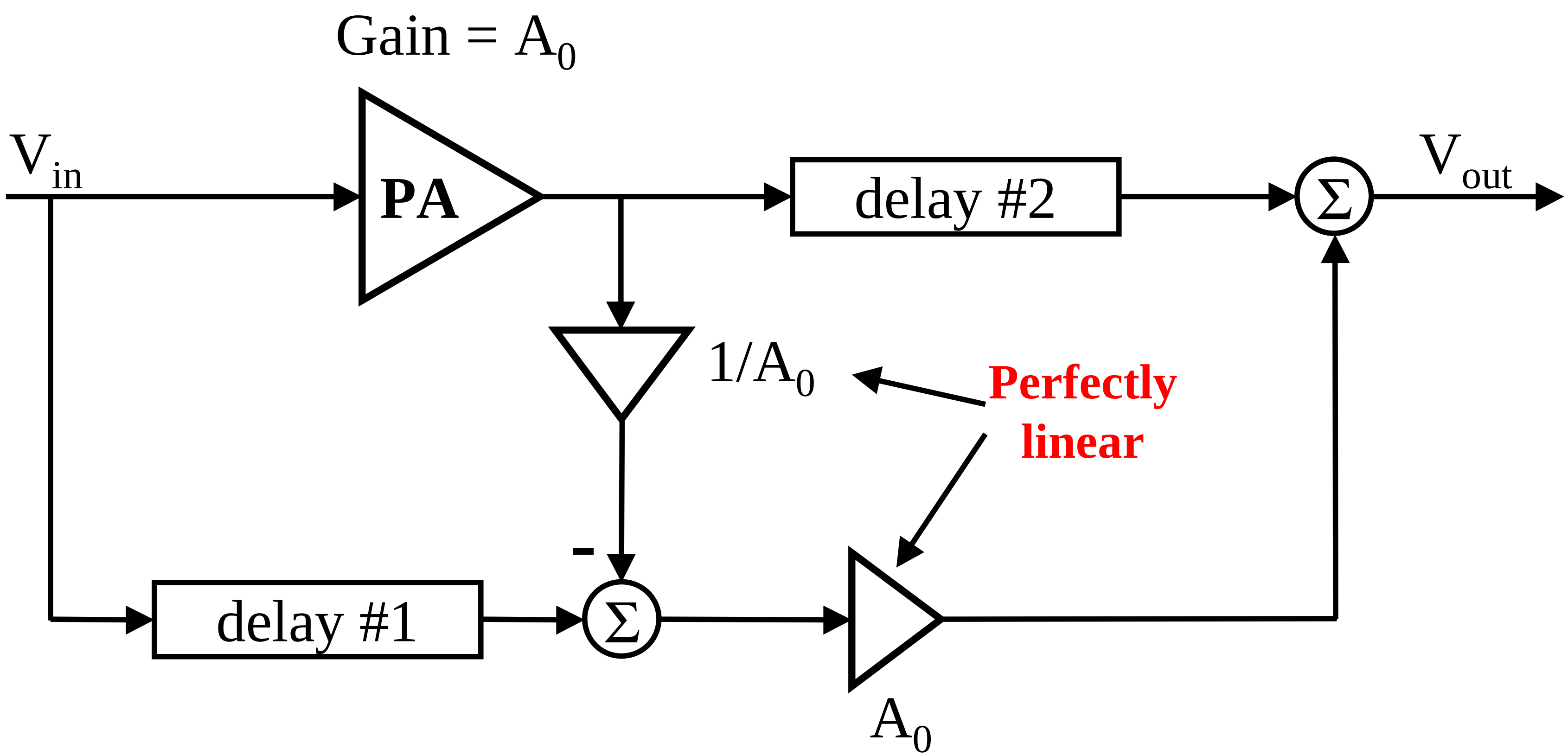
Adaptive Predistortion: advantages

- Does not suffer the bandwidth limitation incurred by continuous-feedback techniques.
- Solves the problem of drift sensitivity.

Adaptive Predistortion: design issues

- New, discrete-time feedback stability problem associated with model estimation.
- Depends on having a good power amplifier model.
- Complexity: incurs power overhead of a DSP chip.

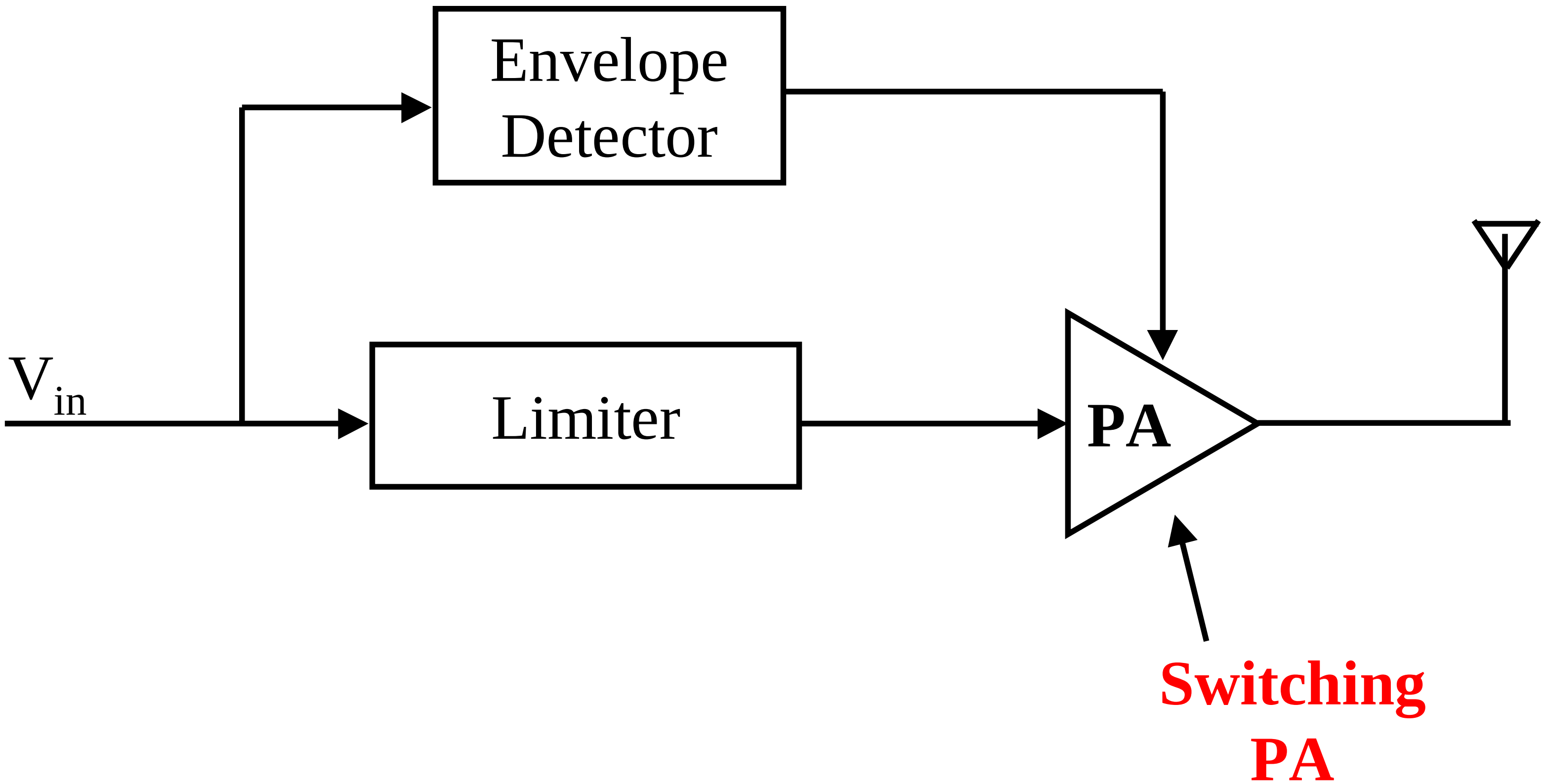
Technique IV: Feedforward Linearization



Feedforward: stable, but...

- Matching delay lines, amplifier gains not trivial.
- Susceptible to drift and aging.
- Low-loss delay lines, summations critical.

Technique V: Envelope Elimination and Restoration

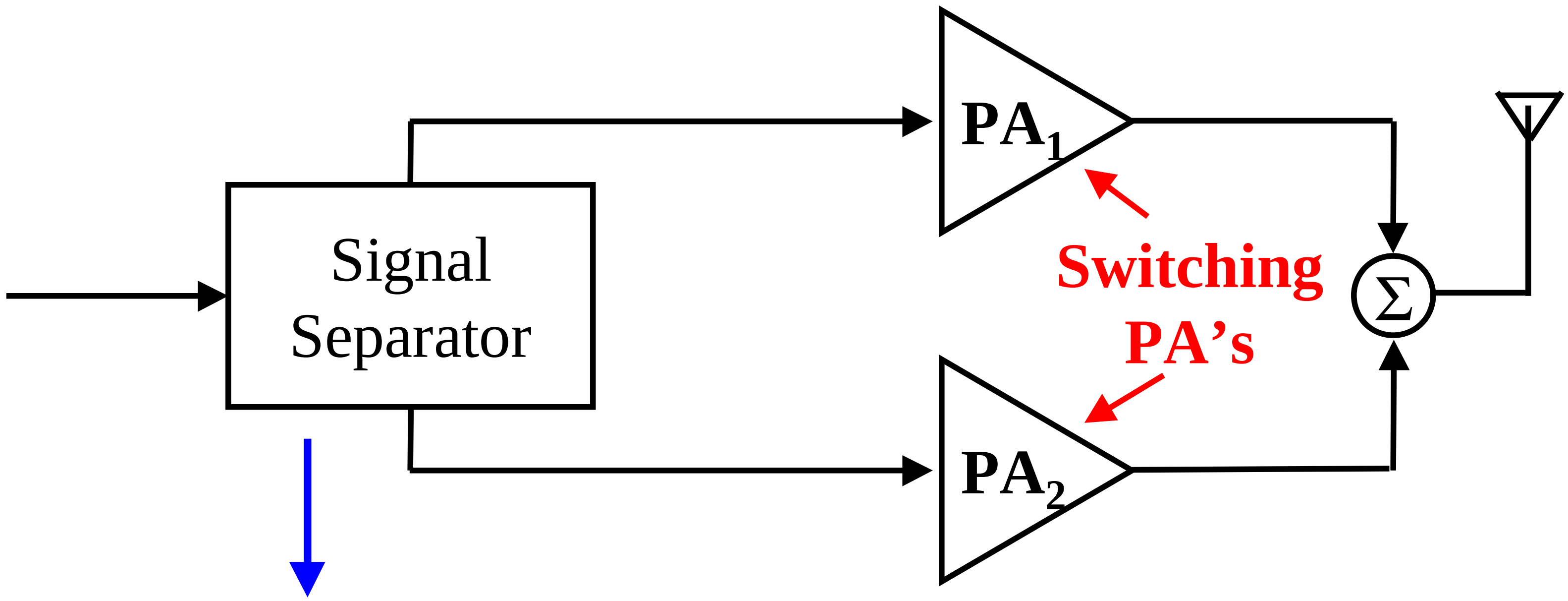


EER design issues

- Phase matching between the two signal paths critical.
- Polar feedback a possibility.
- Restoring the envelope in a power-efficient way is very challenging.

Technique VI: LINC

*LI*near amplification with *N*onlinear *C*omponents



$$a(t)\cos[\omega_c t + \phi(t)] = 0.5V_0 \sin[\omega_c t + \phi(t) + \theta(t)] - 0.5V_0 \sin[\omega_c t + \phi(t) + \theta(t)]$$

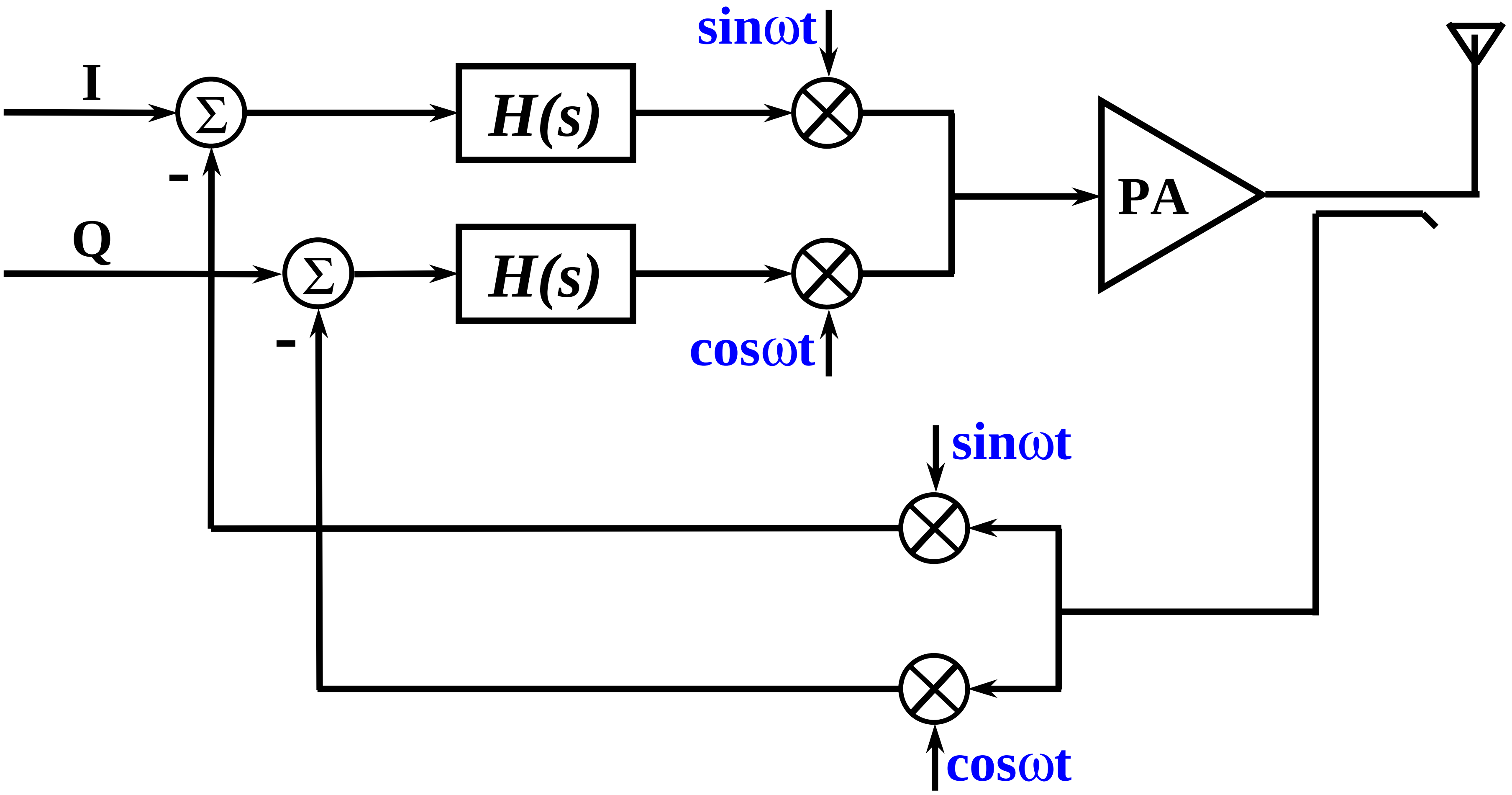
Constant-amplitude terms

$$\theta(t) = \sin^{-1}\left[a(t) / V_0 \right]$$

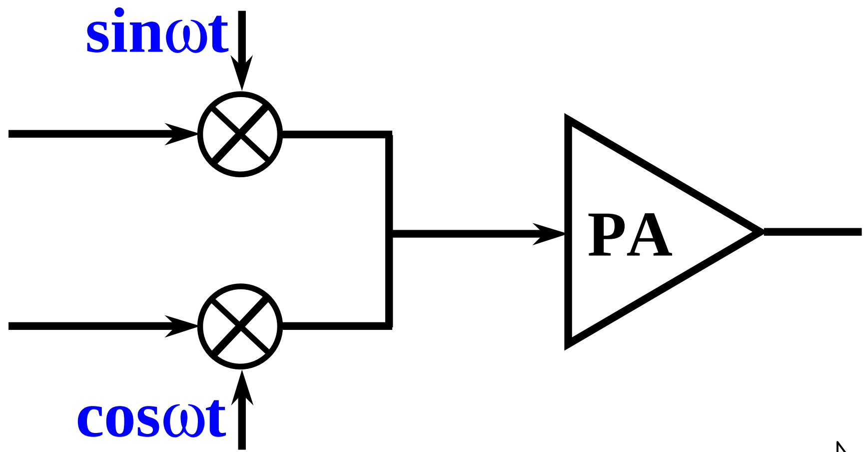
LINC design issues

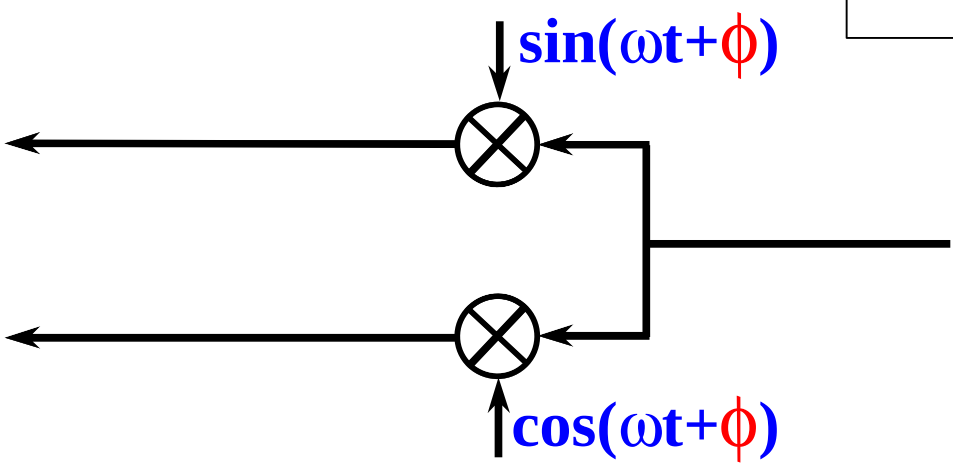
- Signal separation complicated, but possible.
- Good power combining with *low loss and high isolation* is the key barrier.

Technique VII: Cartesian Feedback



Major design consideration in CFB systems: phase alignment





$$L_{eff} = H(s)\cos\phi + \frac{[H(s)\sin\phi]^2}{1+H(s)\cos\phi}$$

CFB Strengths and Weaknesses

- W: Bandwidth limitation
- W: Stability concerns

- S: Low-complexity
- S: Highly resistant to drift and aging
- SS: Robust to poor characterization of PA

Summary

- **Power Backoff**: simplicity; low power efficiency.
- **Predistortion**: conceptually clear; requires good PA model.
- **Adaptive Predistortion**: No drift problem; introduces complexity.
- **Feedforward**: No stability worries; matching and drift concerns.
- **EER**: Possibly high-efficiency; adds another “power amp” problem.
- **LINC**: Conceptually appealing; fundamental implementation issues.
- **CFB**: simplicity, robust to poor PA model; stability concerns.

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Available at the conclusion of ISSCC 2001.